

## PROTALUS RAMPARTS ON NAVAJO MOUNTAIN, SOUTHERN UTAH

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**ABSTRACT.** Protalus ramparts are along the base of the upper slopes of Navajo Mountain and on a prominent topographic bench. They are separated from talus aprons on the flanks of the mountain and other protalus ramparts by ditches which are either free of or partially filled with talus debris. The protalus ramparts are composed of large angular boulders of sandstone. They are between 5 and 80 feet high and were deposited within 500 feet of the slopes of the mountain. The ramparts and ditches between constitute platforms forming distinct breaks in the talus aprons near the base of the upper flanks of the mountain. The talus platforms are composed of either one, two, or three protalus ramparts. They have an average length of 300 feet and a width of 200 feet.

The degree of weathering and physiographic expression indicate that the talus platforms developed during the Wisconsin and are of two ages. The older may be correlative with the Bull Lake Glaciation, and the younger may be assigned to the Pinedale Glaciation of the Rocky Mountain region. The individual ridges in the talus platforms probably developed during distinct periglacial stades. Elevations of the Wisconsin regional and orographic snow lines in the southwestern United States demonstrate that the protalus ramparts formed near the orographic snow line along seasonal snow banks above timber line.

### INTRODUCTION

*Location and general geology.*—Navajo Mountain is in the Canyon Lands section of the Colorado Plateau in southern Utah about 7 miles south of the confluence of the San Juan and Colorado Rivers (fig. 1). It is on the Navajo Indian Reservation and is 140 miles northeast of Flagstaff, Arizona. The crest of the mountain is reached by a primitive road extending westward from Navajo Mountain Trading Post on the eastern flank.

Navajo Mountain is a broad structural dome about 6 miles in diameter and slightly elongated in a northeasterly direction. It is composed of Mesozoic sedimentary rocks which dip in all directions from the top and was probably formed by one or more laccolithic intrusions of late Cretaceous or early Tertiary age. The crest has an elevation of about 10,000 feet and rises approximately 4000 feet above the surface of the surrounding Rainbow Plateau. The lower flanks are formed by the Navajo Sandstone of Triassic (?)–Jurassic age and are eroded into jagged promontories, spires, and pinnacles. Many steep walls, 1000 feet or more in height, are along the short, deep canyons that dissect the lower slopes. A topographic bench, here referred to as War God Bench, terminates the rugged lower flanks on the eastern and southern sides (fig. 2). This physiographic feature has an elevation of about 8500 feet. It slopes gently southeastward and is underlain by the Carmel Formation and Entrada Sandstone of Jurassic age. A smaller bench on the western flank of the mountain near Horse Canyon is underlain by the same stratigraphic units and has a similar altitude.

The upper slopes rise 1500 feet above War God Bench and are formed by the Entrada Sandstone and Morrison Formation of Jurassic

age and possibly the Dakota Sandstone of Cretaceous age (Baker, 1936, p. 60). They are as steep but less dissected than the lower flanks. The crest of the mountain is a relatively flat area about half a square mile in extent. Two large amphitheatres are eroded in the northeastern and southwestern flanks at the heads of Horse Canyon and Cha Canyon. These features have steep walls rising about 2000 feet above their floors and have been considerably dissected by streams.

*Vegetation and climate.*—Of the six life zones generally present throughout northern Arizona and southern Utah, four are found in the vicinity of Navajo Mountain. The Upper Sonoran zone, characterized by pinon and juniper, ranges from 6500 to 8500 feet; the Transition zone, distinguished by Ponderosa pine and Douglas fir, extends between 6500 and 9000 feet. Spruce and fir diagnostic of the Canadian and Hudsonian zones grow on the upper flanks from about 9000 feet to the crest.

The elevation of these life zones on Navajo Mountain is controlled by slope exposure and topography as well as altitude. The zones are generally lower on the northern and eastern flanks than on the southern and western and are depressed approximately 1000 feet in the two amphitheatres. On War God Bench, where most of the protalus ramparts are found, Ponderosa pine and Douglas fir are present as well as groves of aspen and sage brush in open parks.

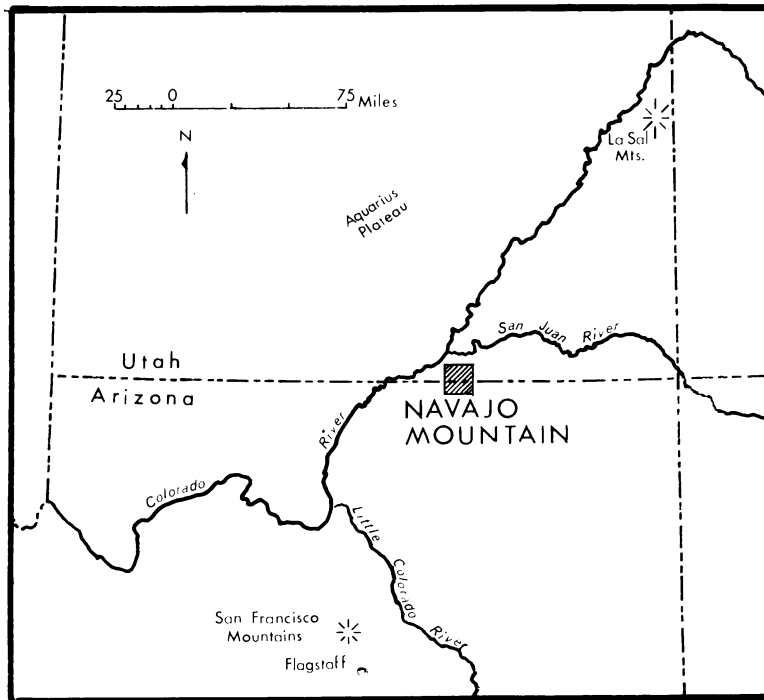


Fig. 1. Location of Navajo Mountain.

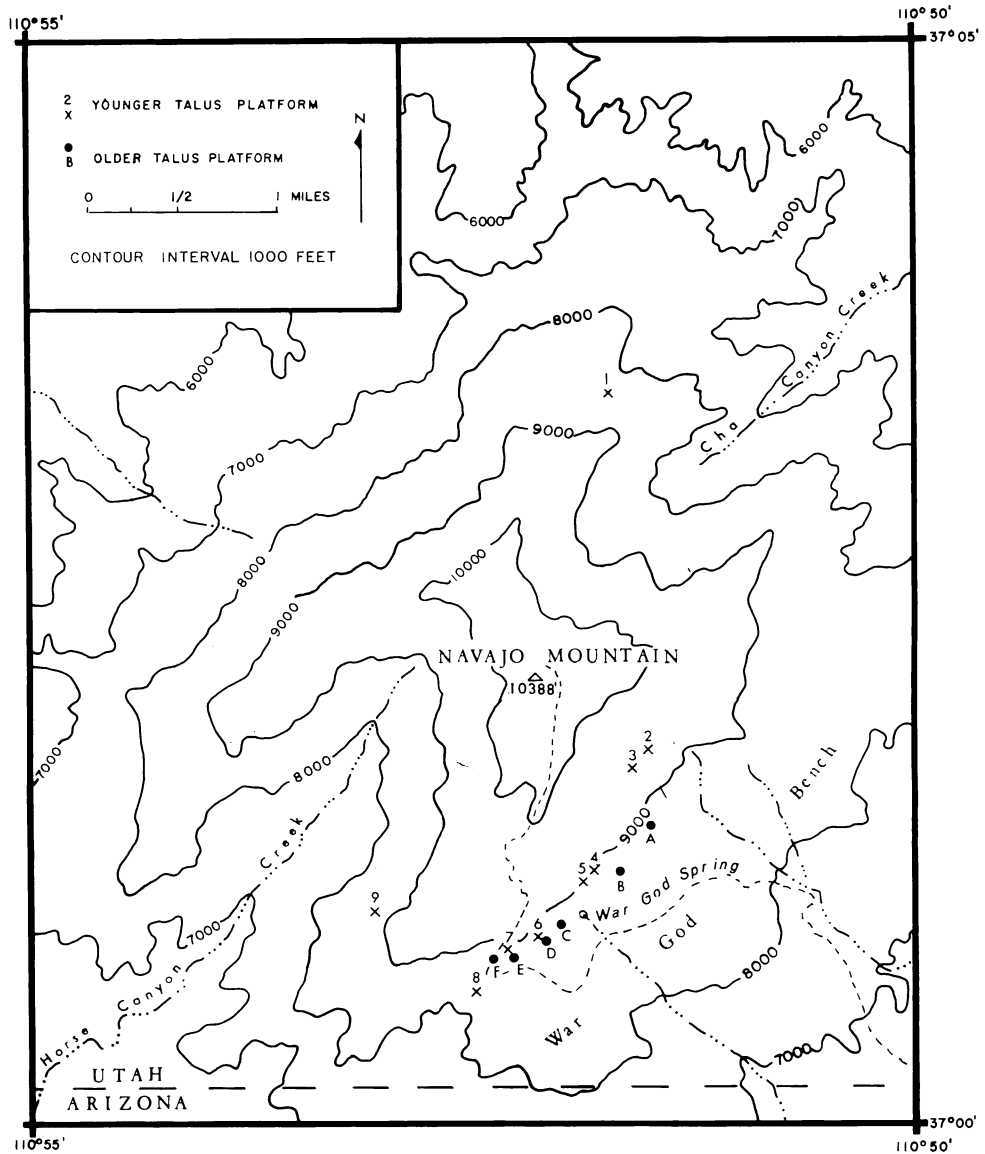


Fig. 2. Location of older and younger talus platforms on Navajo Mountain.

No climatic records are available for Navajo Mountain, but the vegetation shows that the climate is more humid and the temperature lower than in the surrounding terrain. Estimations of meteorological conditions can be made from the life zones but should be considered approximations. The mean annual temperature on War God Bench is probably about 45 degrees, and the annual rainfall is approximately 20

inches. The crest of the mountain may have a mean annual temperature of 40 degrees and receive about 25 inches of precipitation a year.

*Periglacial features.*—Periglacial processes have been extremely active on Navajo Mountain above 8500 feet. Stabilized and active talus sheets, some of which are acres in extent, cover the upper slopes above the benches. This debris is formed by angular blocks 6 inches to 3 feet in diameter derived from the Summerville and Morrison Formations and possibly the Dakota Sandstone. Talus covers the walls of the two amphitheaters and encroaches upon the floor of Cha Canyon at an elevation of about 8000 feet. The deposits take the form of sheets, lobes, and tongues and are composed of fragments of sandstone derived from the walls.

Talus has accumulated along the base of the upper slopes of the mountain and on War God Bench immediately below. It is composed of large angular blocks of sandstone and forms a nearly continuous apron on the southwestern, southern, and eastern flanks. Locally protalus ramparts have developed within 500 feet of the talus-covered slopes.

Protalus ramparts were first described and interpreted by Daly (1912, p. 593) and were later named by Bryan (1934, p. 656). Richmond (1962, p. 20) defines a protalus rampart as "a ridge of rubble or debris that has accumulated piecemeal by rock fall or debris fall across a perennial snow bank, commonly at the foot of a talus". Protalus ramparts develop most commonly in cirques at the base of perennial snow banks or firn, and their debris is supplied by frost wedging (Flint, 1957, p. 99). Behre (1933, p. 630) studied protalus ramparts in the Rocky Mountain region and concluded that many ridges formed above timber line at the base of residual snow banks after the winter snow had disappeared from most of the landscape. The snow banks were between the mountain cliffs and valleys in protected localities.

#### PROTALUS RAMPARTS

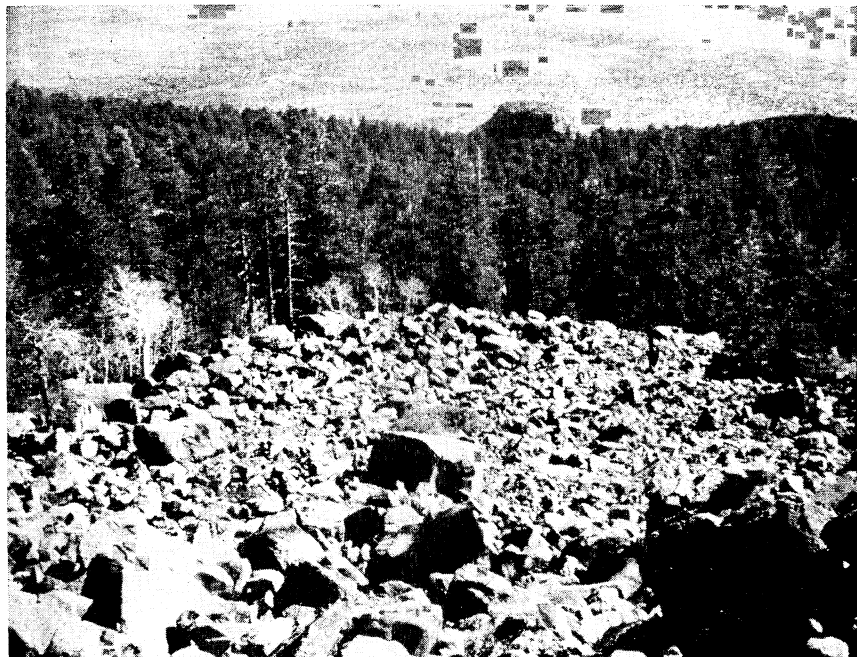
Protalus ramparts are most numerous along the base of the upper slopes of Navajo Mountain on the southeastern flank. They have also been observed on the northern and western slopes. The ridges are separated from other protalus ramparts and talus aprons on the flanks of the mountain by ditches that are either free of or partially filled with talus debris. At many localities protalus ramparts and ditches constitute platforms forming distinct breaks in talus slopes near the base of the upper flanks of the mountain.

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#### PLATE I

A. Younger talus platform 5 on southeastern slope of Navajo Mountain. Large blocks are on crest of outer ridge. Arrow identifies middle protalus rampart. Smaller debris is in the ditches. Large blocks comprising talus apron on the upper slope of the mountain are in the foreground.

B. Older talus platform E on southern flank of Navajo Mountain. Man to left is on outer protalus rampart. Most of the talus is covered by a soil developed on sand and silt of probable colian origin. Man to right is near the center of the platform.



A.



B.

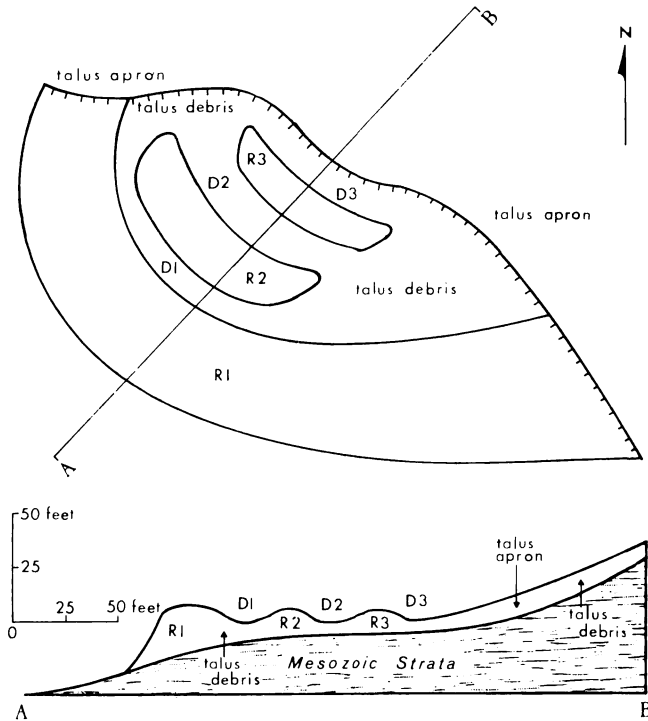


Fig. 3. Map and profile of younger talus platform 6 on southern slope of Navajo Mountain. Protalus ramparts and ditches are delineated: R1, outer protalus rampart; R2, middle protalus rampart; R3, inner protalus rampart; D1, outer ditch; D2, middle ditch; D3, inner ditch.

Talus platforms of two ages are distinguished by the extent to which their constructional topography is preserved and the amount of soil and vegetation cover. The younger platforms have pronounced physiographic expression characterized by well-defined ramparts and distinct ditches. They lack a soil cover and contain a sparse growth of trees and shrubs (pl. 1-A). The talus debris is slightly weathered and has a moderate coat of desert varnish. Talus blocks have a moderate to heavy growth of lichen on their exposed surfaces and are completely stabilized. No apparent variation in the intensity of lichen growth and desert varnish was observed on the debris forming the younger platforms and that of the talus aprons.

Older talus platforms have a subdued constructional topography distinguished by a moderate expression of the ramparts and scant delineation of the ditches. They are partially covered by about 6 inches of sand and silt of probable eolian origin and a growth of trees and shrubs (pl. 1-B). A dark brown soil about half an inch thick containing much organic material has developed on the sand and silt. Talus debris is only moderately well exposed on the ridges and is nearly always obscured over the

rest of the platform. The blocks are covered with lichen and desert varnish and are moderately to slightly weathered.

*Younger talus platforms.*—Nine younger talus platforms have been mapped on Navajo Mountain (fig. 2). They have elevations ranging between 8400 and 9220 feet, and their surfaces slope from the flanks of the mountain with angles varying between 6 and 16 degrees. The platforms face in all major quadrants of the compass, but southern and south-eastern exposures are most prevalent. They are both arcuate and parabolic in form and are composed of one, two, or three protalus ramparts.

The protalus rampart furthest from the slope of the mountain is generally the largest on compound talus platforms and forms the outer wall (figs. 3 and 4). This outer ridge surrounds the smaller protalus ramparts and debris in the ditches and abuts against the flank of the mountain on its two termini. The inner ridge is usually the smallest, and the middle protalus rampart is intermediate in size. Three ditches or depressions are on talus platforms containing three protalus ramparts, and the outer separates the outer ridge from the middle. The middle ditch is between the middle and inner protalus rampart, and the inner depres-

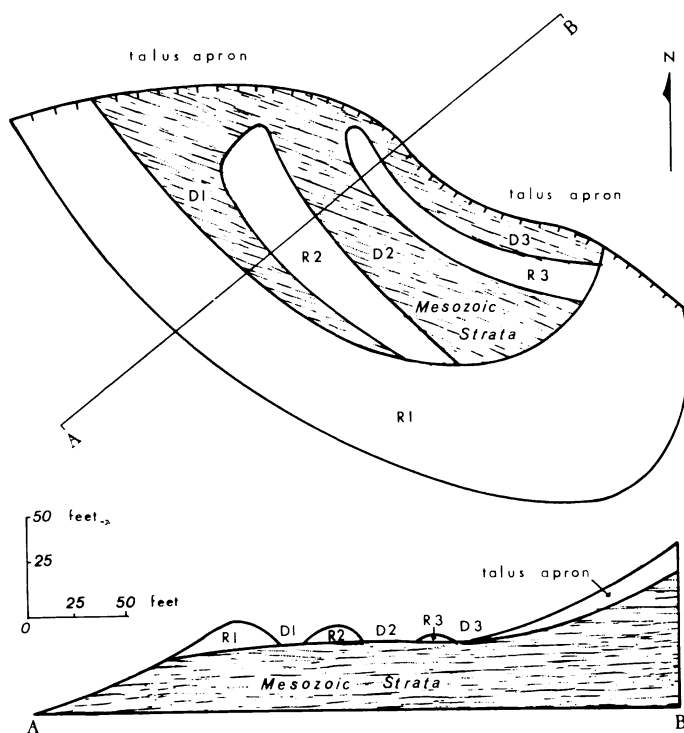


Fig. 4. Map and profile of younger platform 8 on southern flank of Navajo Mountain showing protalus ramparts and ditches (see pl. 2-A). R1, outer protalus rampart; R2, middle protalus rampart; R3, inner protalus rampart; D1, outer ditch; D2, middle ditch; D3, inner ditch.

sion divides the inner ridge from the talus aprons on the flanks of the mountain. Middle and inner protalus ramparts are either separated from the talus aprons by small depressions contiguous with and at the same level as the floors of the ditches or abut against the outer ridges (figs. 3 and 4).

Considerable variation exists in the size of the younger talus platforms and the ramparts and ditches that compose them. Average length measured along the base of the mountain is about 300 feet, and the width determined at right angles to the length is approximately 200 feet. Outer protalus ramparts are between 10 and 80 feet high and have breadths measured at their bases from 45 to 120 feet. Crests of the middle and inner ridges are between 5 and 30 feet above the floor of the depressions, and their widths are considerably less than those of the outer protalus ramparts. Ditches have breadths ranging between 10 and 50 feet. They are arcuate shaped and generally parallel the protalus ramparts.

Three types of younger talus platforms are distinguished by the extent to which debris covers the floors of the ditches. Seven are characterized by a veneer of talus in the depressions and around the middle and inner protalus ramparts (pl. 1-A and fig. 3). Thickness of the debris is between 5 and 10 feet, and the protalus ramparts are from 10 to 30 feet above the debris-covered floor. Platform 8 on the southern side of the mountain is a second type distinguished by an almost complete absence of talus between the ramparts (pl. 2-A and fig. 4). The ditches are broad, flat depressions underlain by bedrock, and the protalus ramparts stand out as distinct ridges. A third type is represented by platform 9 on the western flank and is characterized by a partial cover of debris on the floors of the outer and middle ditches (pl. 2-B). Talus extends into the depressions from the middle and inner protalus ramparts. Bedrock crops out on the floor in small arcuate-shaped areas directly behind the outer and middle ridges.

Debris forming the younger talus platforms and talus aprons is composed of angular blocks of sandstone derived from the Mesozoic strata exposed on the upper slopes of the mountain. Many of the fragments are rectangular in shape, the result of the intersection of joint surfaces and bedding planes. The blocks have maximum diameters ranging between 10 and 15 feet and minimum diameters of about 3 feet. Subangular to subrounded fragments have dimensions varying from 6 inches to 1 foot and fill the spaces between the larger blocks. In some compound talus platforms the outer ridge is composed of slightly larger fragments than the middle and inner protalus ramparts. In others there is no apparent difference in size. Boulders forming the ramparts and partially filling the ditches are randomly distributed with no orientation imbricate to the slope of the platforms.

Talus debris on the floors of the ditches and on the flanks of the protalus ramparts is smaller than on the crest of the ridges and on the surfaces of the talus aprons (pl. 1-A). This relationship suggests that the larger blocks are segregated on the crests of the ramparts and may cover



A.



B.

PLATE 2

A. Middle protalus rampart of younger talus platform 8 on southern side of Navajo Mountain. Blocks in foreground are part of talus apron. Ditch between talus apron and middle protalus rampart is almost free of debris (see fig. 4).

B. Younger talus platform 9 on western slope of Navajo Mountain. Man to right is on outer protalus rampart. Debris in foreground extends from middle protalus rampart and has partially filled the outer ditch.

smaller debris. On many of the talus platforms the average diameter of the smaller fragments is about 3 feet as opposed to 6 feet for the larger blocks. On others only a slight difference in size was observed between the larger and smaller debris.

*Older talus platforms.*—Six older talus platforms are on the southern and eastern flanks of Navajo Mountain along War God Bench. They are more difficult to recognize than the younger because of their degree of modification and soil cover. Other platforms not shown in figure 2 may be in the heavily forested areas along the base of the upper slopes. The older talus platforms are between 20 and 200 feet below the younger and, in some instances, are separated from them by talus-covered slopes (fig. 5). The talus debris was probably deposited during formation of the younger protalus ramparts and talus aprons and encroaches upon the floor of the older platforms.

Older talus platforms resemble the younger in size and form and are composed of angular blocks of sandstone with average diameters of about 6 feet. They contain one or two recognizable protalus ramparts behind and around which talus debris has accumulated. The older talus platforms have average elevations of 8740 feet. Their surfaces slope from the cliffs rising above War God Bench and are not dissected by the intermittent streams eroded in the upper flanks of the mountain. The outer ridges are the larger and constitute walls containing the inner protalus ramparts and debris on the floors of the ditches. They abut against the slopes of the mountain on their two termini and have average heights of about 25 feet.

#### ORIGIN AND CLIMATIC IMPLICATIONS

Protalus ramparts are ridges of coarse blocks and boulders that accumulated in front of snow banks or temporary firn fields. The boulders rolled, slid, or bounced across the snow or firn and accumulated at the base. No fine material moved with the coarse talus because the fine debris cannot roll, slide, or bounce across snow or firn (Sidney E. White, written communication, 1967). Protalus ramparts are easily confused with

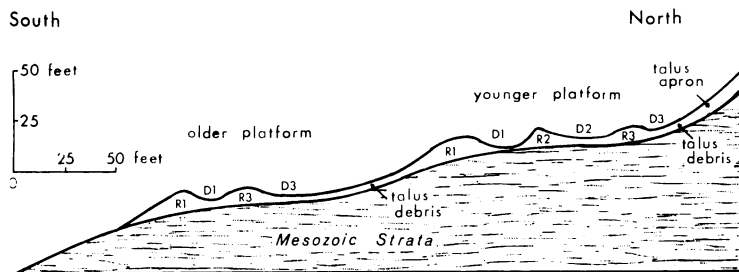


Fig. 5. Profile of older talus platform E and younger talus platform 7 on southern flank of Navajo Mountain. Protalus ramparts and ditches are delineated (see pl. 1-B). R1, outer protalus rampart; R2, middle protalus rampart; R3, inner protalus rampart; D1, outer ditch; D2, middle ditch; D3, inner ditch.

protalus lobes defined by Richmond (1962, p. 20) as "a tongue-like or lobate mass of rubble or debris that is the product of creep or solifluction of the debris toe of a talus". Protalus lobes may contain one or more arcuate ridges in which the blocks tend to be oriented imbricate to the slope (Richmond, 1962, p. 61). The lobes are composed of all the various sizes of fragments that constitute the parent talus and may contain fine as well as coarse debris (Sidney E. White, written communication, 1967). The ridges on Navajo Mountain are protalus ramparts rather than protalus lobes because they are well-defined and separated from the talus-covered slopes of the mountain and other protalus ramparts by ditches, some of which are free of debris. They are also distinguished by their lack of fine debris which along with coarse blocks composes the talus aprons on the flanks of the mountain.

The protalus ramparts on Navajo Mountain are believed to be of Wisconsin age for the reasons given below. They were first observed by Gregory (1917, p. 82) who attributed them to "incipient ice work" and "nivation operating at a time when a perennial snow cap occupied the highland". This origin implies that the ridges formed above the orographic snow line because ice and permanent snow fields are assumed. An evaluation of the altitudes of the Wisconsin regional and orographic snow lines in southwestern United States indicates that the protalus ramparts probably accumulated near the orographic snow line, and the more extreme climatic conditions suggested by Gregory were not necessary for their development.

The regional snow line is defined by Matthes (1940) as "the level above which snow accumulates from year to year to generate ice bodies over a large part or all of the land depending upon latitude, altitude, and topography". It is approximated by the lower limit of ice caps (Richmond, 1965, p. 228). Orographic snow line is the lower limit of small, isolated snow banks and patches of névé which owe their preservation to favorable mountain surroundings (Ray, 1940, p. 1911).

The elevation of the Wisconsin regional snow line on the Aquarius Plateau 80 miles northwest of Navajo Mountain in south-central Utah was somewhat below 11,000 feet (Flint and Denny, 1958, p. 160). Its altitude over Navajo Mountain was probably slightly higher because the regional snowline rises to the southeast in the western United States (Ray, 1940, p. 1911), and it is estimated to have been at about 11,000 feet. At the present time the orographic snow line may impress itself 2500 feet below the regional snow line in the Sangre de Cristo Mountains of southern Colorado and northern New Mexico (Richmond, 1965, p. 225, fig. 3). If today there is such a difference between the orographic and regional snowlines at these latitudes, it is assumed that this was true in the Pleistocene, and the Wisconsin orographic snow line on Navajo Mountain may have been at about 8500 feet.

The protalus ramparts on Navajo Mountain formed between 8400 and 9200 feet or close to the postulated Wisconsin orographic snow line. Thus the snow banks responsible for their development probably melted

considerably or disappeared completely at the end of each summer. This would have been particularly true for those on the southern and western flanks of the mountain. The spring and early summer were opportune times for the dislodgment of blocks by frost wedging because of diurnal freezing and thawing and saturation from water supplied by melting snow. During this season the snow banks maintained a fairly constant size since the debris accumulated as ridges at their bases. As the snow banks began to melt later in the summer, frost wedging diminished, and the supply of blocks dwindled; otherwise the ditches would have become filled during their retreat. This balance between the supply of debris and persistence of the snow bank must have existed each spring and early summer for a considerable number of years in order for the ridges to develop.

The segregation of larger blocks on the crest of many of the protalus ramparts on Navajo Mountain gives an indication as to their origin and the climatic conditions under which they developed. Many of the boulder fields in the Driftless Area of Wisconsin show this same relationship (Smith, 1949, p. 212). The smaller debris is thought to have been derived by frost action from a weathered zone developed during an interglacial stage when chemical weathering was prevalent. The coarser debris formed after the fine material had been removed by gravity and frost induced slope processes. It was derived from deeper bedrock in which there had been less preparation by previous chemical weathering. Hence, only the more persistent and through-going joints offered points of attack and only large blocks were dislocated.

If the same reasoning is applied to the ridges on Navajo Mountain, it can be postulated that many protalus ramparts are composed of talus formed during two stages of weathering. The smaller debris was deposited at the beginning of a periglacial stade and was derived from terrain that had undergone chemical weathering in an interperiglacial stade. The larger blocks were dislodged by frost wedging and deposited a considerable time after the onset of periglacial conditions. This interpretation suggests that several of the younger talus platforms may have formed during three distinct periglacial stades separated by two interperiglacial stades because they contain three well-developed protalus ramparts.

The excellent development of protalus ramparts on Navajo Mountain may be attributed in part to the lithology and structure of the Mesozoic strata, which form the upper slopes and crest of the mountain. These stratigraphic units are especially susceptible to weathering by frost wedging because they contain porous, well-cemented sandstone beds with well-developed joint surfaces and bedding planes. After the blocks were dislodged, gravity carried them down the upper flanks of the mountain, and they accumulated near the break in slope at the foot. The base of the upper slopes was a favorable area for the formation and preservation of snowbanks during periglacial stades. Irregular cliffs ris-

ing above the topographic benches acted as a windbreak, causing the development of large snowdrifts in the winter, and provided shade in the warmer seasons enabling the snowbanks to persist well into the summer.

#### AGE AND CORRELATION

The talus platforms are believed to be of Wisconsin age because the degree of weathering of the talus debris and the physiographic expression of the ridges and ditches preclude them from being older, since the chief characteristics of pre-Wisconsin deposits in the Cordilleran region of North America are the development of a very thick, mature soil with little evidence of constructional topography remaining (Flint, 1957, p. 329). Weathering of the talus on Navajo Mountain has been slight to moderate, and the boulders lying near the surface show little decomposition and chemical alteration. Soil on the older talus platforms is only about half an inch thick and has developed upon sand and silt of probable eolian origin rather than on material formed from decomposition of the talus. The talus platforms are little dissected and still maintain their constructional topography, even though they are at the base of steep slopes where erosion is intense. The younger talus platforms are modified very little, and the older still maintain well-defined ridges in spite of considerable change. No other protalus ramparts, till sheets, or moraines of any glaciation have been observed below or above the protalus ramparts here described. This suggests that the protalus ramparts are not either pre-Wisconsin or Neoglaciation in age.

The periglacial deposits on Navajo Mountain probably formed during glacial substages of the Wisconsin because the same climatic changes that caused glaciers to develop in the higher mountain ranges of the Colorado Plateau and Rocky Mountain region would also produce periglacial environments on the mountain. The older and younger talus platforms probably developed during separate Wisconsin substages since the degree of modification of the older indicates a considerable time lapse between their formation and that of the younger.

The talus platforms may be correlated with the Wisconsin glacial deposits of the Colorado Plateau and Rocky Mountain region using physiographic similarities and degree of weathering as criteria. Two substages of Wisconsin glaciation are recognized in the La Sal Mountains of eastern Utah (Richmond, 1962), on the Aquarius Plateau in southwestern Utah (Flint and Denny, 1958), and on the San Francisco Mountains of northern Arizona (Sharp, 1942). These uplands are on the Colorado Plateau and are the three glaciated areas nearest to Navajo Mountain (fig. 1). The two substages are correlative with the Bull Lake and Pinedale glaciations in the Rocky Mountain region, and minor end moraines, protalus ramparts, and rock glaciers of Recent age are assigned to the Neoglaciation (Flint, 1957, p. 329; and Richmond, 1965, p. 222-223).

Throughout the Rocky Mountain region and Colorado Plateau, the Bull Lake drift has subdued constructional topography and is moderately weathered. A soil separates it from overlying glacial deposits

at some localities. The Pinedale drift is less extensive than the Bull Lake. It has pronounced constructional topography and shows little alteration by weathering. The Neoglacial deposits are very little affected by weathering and have exceedingly well-developed constructional topography. The older talus platforms on Navajo Mountain are probably correlative with the Bull Lake Glaciation because they have moderate expression of the protalus ramparts and ditches and are partially obscured by a thin soil. The younger talus platforms may have formed during the Pinedale Glaciation since they have well-developed ridges and depressions, lack a soil cover, and have undergone little weathering. Some of the debris forming the talus aprons on the flanks of the mountain probably accumulated during the Neoglaciation after the formation of the younger protalus ramparts.

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